Forest Health Technology Enterprise Team

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BIOLOGICAL CONTROL

Biological Control of Hemlock Woolly Adelgid in the Eastern United States

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Photo montage shows (1) [illegible] cottony ovisacs, each containing up to 300 eggs — the most obvious sign of infestation, (2) adult coccinellid (*Pseudoscymnus tsugae*) predator feeding on ovisacs, and (3) HWA damaged trees. Photos are courtesy of the author and Brad Onken of the Northeastern Area, State and Private Forestry, Morgantown Field Office.

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Information and Copies

For information concerning natural enemies of hemlock woolly adelgid, please contact The Connecticut Agricultural Experiment Station at (860) 683-4977, or for copies of this publication, contact Dr. Richard Reardon at (304) 285-1566 (email: rreardon@fs.fed.us).

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Introduction

The hemlock woolly adelgid, *Adelges tsugae* Annand (Homoptera: Adelgidae), is a small insect that feeds on stored nutrients from young twigs of hemlocks. The resulting loss of needles and new shoots can seriously impair tree health. Populations of hemlock woolly adelgid (HWA) on ornamental hemlocks can be controlled by applying chemical insecticides. In the forest, however, the best hope of controlling adelgid populations is by biological control using natural enemies (parasitoids, predators, pathogens). At this time, there are no known parasitoids of HWA while native predators and pathogens are not capable of maintaining HWA populations at non-damaging levels. As an alternative, scientists are placing emphasis on rearing and releasing a complex of non-native predators.

Distribution

HWA is native to Asia, where it is a harmless inhabitant of several hemlock (*Tsuga*) species. It is present in Japan, India, southwestern China, and Taiwan. HWA (***Figure 1***) was first observed in North America in the 1920's on western hemlock (*T. heterophylla)* and

Figure 1. Hemlock woolly adelgid ovisacs containing eggs on the underside of a hemlock branch.

mountain hemlock *(T. mertensiana)* in Oregon and British Columbia. HWA has now been found from northern California to southeastern Alaska where it is generally harmless and not considered a pest.

HWA was first observed in the eastern United States around 1950 in Richmond, Virginia. Since then, it has spread into 12 states on the eastern seaboard from North Carolina to New England, where it is a serious pest of eastern hemlock (*T. canadensis)* (***Figure 2***). HWA also attacks Carolina hemlock (*T. caroliniana)*, a rare species that occurs in isolated pockets in Virginia, North Carolina, South Carolina, and Georgia. In the past 15 years, the main front of the HWA infestation has been advancing at a pace of approximately 15 miles per year. However, from time to time isolated infestations have been discovered well away from the main front.

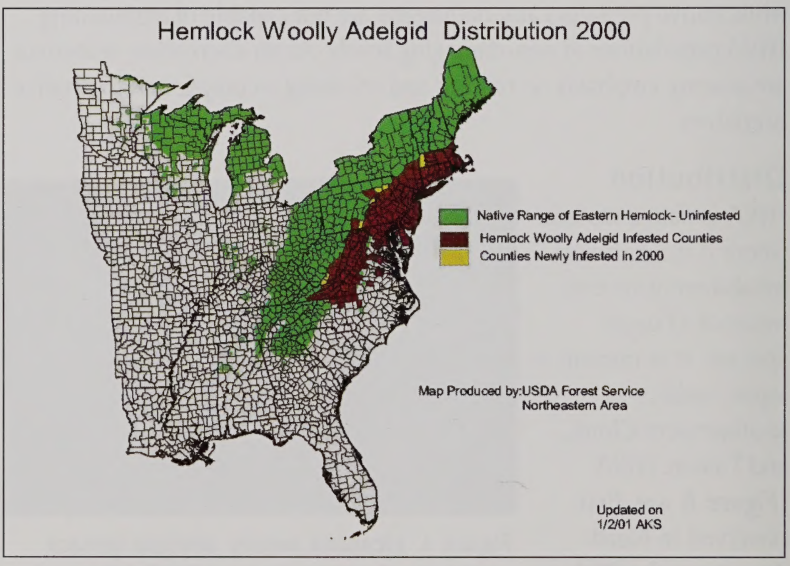

Figure 2. Native range of eastern hemlock (in green) and range of hemlock woolly adelgid (in red) as mapped in 2000.

HWA spreads mainly as eggs and crawlers (or mobile immatures of the insect that hatch from the eggs), which are carried by wind, birds, other forest animals, and people. Because HWA survives in central Japan where winter temperatures drop below –35°C and summer temperatures exceed 40°C, it will probably continue to spread and threaten eastern and Carolina hemlocks throughout much of their natural ranges in North America where similar climatic conditions exist.

Biology and Damage

On hemlock, HWA is parthenogenetic, that is, all individuals are females capable of reproducing. HWA populations build rapidly because a single female lays up to 300 eggs. Two generations of HWA are produced in an annual cycle.

Feeding by HWA on eastern and Carolina hemlocks causes the needles to desiccate (dry up), turn grayish-green, and drop from the tree – usually within a few months (***Figure 3***). Most buds are also killed, so little if any new growth is produced on infested branches. Once a tree becomes heavily infested, dieback of major limbs usually occurs within two years, and trees often die within four years. Some infested hemlocks survive longer with only a sparse amount of foliage at the very top of the crown. Severely weakened hemlock trees are unsightly and have little chance for recovery. Weakened trees often fall victim to other insects and diseases, and are easily broken, and thrown by wind.

Figure 3. Hemlock branch shows heavy infestation of hemlock woolly adelgid.

Figure 4a-b. Adult (left) and larval (right) stages of the coccinellid beetle *Pseudoscymnus tsugae*.

Natural Enemies

In Japan a predatory beetle and a mite help control HWA on the two native hemlocks, *T. diversifolia* and *T. sieboldii*, and even on highly susceptible eastern hemlock. A coccinellid or lady beetle, *Pseudoscymnus tsugae*, discovered by the author in Japan in 1992, is the most common and effective predator of HWA in that country (***Figure 4a-b***). *P. tsugae* was found in 24 of 74 infested forests and ornamental plantings sampled, where mortality was 86%-99% of all adelgids. Both the larvae and adults of the beetle feed on all growth stages of HWA.

The oribatid mite (*Diapterobates humeralis)* was found in 40 of the 74 sites, where the mite almost completely destroyed (91%-98%) all adelgid eggs. The mite eats the woolly material surrounding the eggs, but not the eggs. Thus, without the protection of the woolly material, the eggs are dislodged and fall to the forest floor where they either dry up or are eaten by ants and spiders.

Focus of Biological Control

In the United States, there are only a few native predators, such as chrysopid and hemerobiid lacewings, syrphid flies, and cecidomyiid flies, attacking HWA. This complex of native predators has not controlled HWA populations. For this reason, efforts since 1992 have

focused primarily on the development and use of introduced biological control agents as a means to lessen the destruction of HWA in the eastern United States.

Initial efforts by the author's research team at The Connecticut Agricultural Experiment Station, based in Windsor, CT, concentrated on *P. tsugae* and the mite, *D. humeralis*. This mite (*D. humeralis)* is no longer considered a viable candidate for biological control for several reasons, including its inherent low fecundity. *P. tsugae,* however, is amenable to mass culturing. Three or more generations can be reared each year in the laboratory on live adelgids under controlled temperature conditions.

P. tsugae possesses other qualities that make it an excellent biological control candidate, as follows:

- It is adapted to a wide range of climate conditions.
- It strongly prefers to feed on adelgids.
- It has at least two generations per year.
- Its life cycle is synchronized with that of HWA.
- It has a high searching efficiency and dispersal ability.

China has also been explored for natural enemies and several lady beetles were discovered feeding on HWA. Three of these, all in the genus *Scymnus,* have been imported and are being studied under quarantine by Dr. Michael Montgomery's research team at the USDA Forest Service, Northeastern Research Station, in Hamden, Connecticut. *Scymnus sinuanodulus*, *S. camptodromus*, and *S. ningshanensis* have different life cycles from one another, but all three species produce only one generation each year. All three scymnids favor HWA over other prey and all prefer to feed on HWA eggs, but also will eat other HWA stages. Although having a single generation will make it difficult to mass culture these predators, they are viable candidates for biological control (***Figure 5***).

Figure 5. Adult coccinellid beetles (genus *Scymnus*).

Laricobius nigrinus, a predatory beetle commonly associated with HWA in western North America, has been imported to Virginia for study by Drs. Scott Salom and Loke Kok and their research team at the Virginia Polytechnic Institute in Blacksburg, VA. Although this derodontid beetle also produces only one generation a year, it does have attributes of a biological control candidate. For example, *L. nigrinus* feeding stages are well synchronized with HWA spring generation egg and nymphal stages, it prefers to feed on HWA over other closely related adelgids and other homopteran insects, its larvae feed primarily on eggs while adults feed on all stages, and it completes development only on HWA (***Figure 6***).

Figure 6. Adult derodontid beetle *Laricobius nigrinus*.

Introducing Predators

So far, *P. tsugae* is the only predator that has been released into the field to control HWA. From 1995 to 2000 the author's research team has released more than 160,000 adults of *P. tsugae* in hemlock forests in three states: 18 forests in Connecticut, 2 in Virginia and 1 in New Jersey. Availability of beetles and the nature of the investigation determined the number of beetles released each year.

To determine local impacts of *P. tsugae,* 2,000 to 3,000 beetles were released in 1995 and 1996 onto trees in 15-acre forests located in Connecticut. In 1997, to facilitate the establishment of *P. tsugae* in the northern and southern parts of the adelgid infestation, more than 5,000 beetles were released in several larger forests in Connecticut and Virginia. Most of these sites were later augmented with additional beetles to bring the numbers released to at least 10,000 beetles. Dispersal and long-term impacts over a larger area are being evaluated in studies of releases from 1998 to 2000 of 10,000 to 20,000 beetles in 50-acre forests in Connecticut, New Jersey, and Virginia.

Results have been encouraging when HWA densities on hemlock trees in release areas were compared with those in similar control areas (beetles absent in the area) at least half a mile away. In 1996, adelgid densities on monitored branches in release areas were reduced by 47%- 87% in just five months by a starting population of only 2,400 to 3,600 adult beetles, indicating a remarkable short-term impact of *P. tsugae* on HWA (***Figure 7***) (see next page).

P. tsugae has overwintered, established, reproduced, and spread at these release sites. In forests where *P. tsugae* has been present for at least three years and where at least 10,000 adults were initially released, beetles are now abundant and can be collected from infested trees. Dispersal of *P. tsugae* over more than half a mile was documented at one of the release sites in Connecticut. At new sites

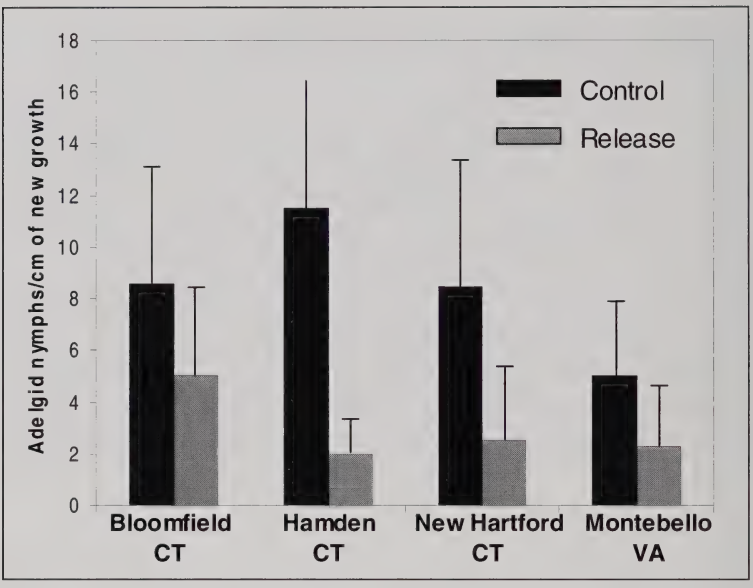

Figure 7. HWA populations on monitored trees at *P. tsugae* release sites.

where 10,000 or more *P. tsugae* adults were released in spring 2000, larvae were observed a few weeks later on release and nearby trees indicating successful reproduction and dispersal. Adult beetles remain on trees year-round, indicating a strong preference for HWA and a high degree of cold-hardiness.

The encouraging results from the cooperative USDA Forest Service State and Private Forestry and The Connecticut Agricultural Experiment Station biological control project spawned an additional cooperative effort with the Phillip Alampi Beneficial Insect Laboratory in Trenton, New Jersey to mass-rear *P. tsugae*. In 1997, the author donated a starter colony of *P. tsugae* to the Alampi Laboratory, and State and Private Forestry provided annual financial assistance to support mass production of *P. tsugae*.

From 1997 through 2000, the Alampi Laboratory produced more than 350,000 beetles for release in New Jersey and eight other eastern states (Maryland, Massachusetts, New York, North Carolina, Pennsylvania, Rhode Island, Virginia and West Virginia). Changes in HWA density and hemlock health as well as the establishment, reproduction and spread of *P. tsugae* at release sites in 10 states in the Northeast are being monitored and recorded annually. Early results from this multistate release effort indicate that *P. tsugae* has established and overwintered successfully in several sites.

Although it is too early to assess the impact of *P. tsugae* on HWA populations and hemlock health at the new release sites, certain trends are evident. A string of relatively mild winters from 1995 to 1999, which enhanced the survival and growth of HWA populations, together with the severe drought of 1999 in the eastern United States, significantly reduced hemlock health and hampered the HWA biological control effort. However, a two-week period with sub-zero (F) temperatures in January 2000 reduced adelgid populations by more than 90% at the northern edge of its range in Connecticut, New York, and New Jersey. The cold weather and the unusually cool and rainy spring and summer of 2000 throughout much of the infested area have allowed hemlocks to recover and flourish, which may enhance the effectiveness of *P. tsugae.*

Outlook

In just a few years, scientists have made good progress in finding and studying potential biological control agents for HWA. *P. tsugae* is the only non-native predator released into the environment, and results in the field have been encouraging thus far.

Additional studies are needed, however, to substantiate that *P. tsugae* will be at least part of the solution to the HWA problem, and to justify

the additional effort and cost required to rear enough beetles for release throughout the HWA-infested area. Managers hope that the beetles will reproduce and spread on their own from release sites to other infested areas. Scientists are developing ways to optimize and reduce the cost of establishing this and other predators throughout the HWA-infested area and to discover other good biological control candidates.

It remains uncertain if any one species will be able to control HWA populations, or if a complex of released predators will be needed.

This pamphlet is available online at
http://www.fs.fed.us/morgantown/fhp/hwa/
hwasite.html

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